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SEA ICE RUBBLE FORMATIONS IN THE BERING SEA AND NORTON SOUND, ALASKA

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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The occurrence of large, compact, grounded pressure ridge formations up to 15 m high in the coastal waters of Norton Sound and the Bering Sea is discussed. These formations periodically float free and drift about, gouging the seabed. Their mass makes them a severe threat to both floating and bottom-founded structures in these waters.

PREFACE

This report was prepared by Austin Kovacs, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Technical review was performed by Dr. Gordon F.N. Cox and Walter B. Tucker of CRREL.

Support of this study was provided by the Bureau of Land Management through the National Oceanic and Atmospheric Administration's Alaska Outer Continental Shelf Environmental Assessment Program.

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INTRODUCTION

The presence of large ice features in the Bering Sea off Alaska was first recorded in the 1800s by seamen navigating these waters. The size of these formations led the sailors to believe that they were icebergs (W.F. Dehn, personal communication). Two photographs of such formations, taken shortly after the turn of the century, show how impressive they can be (Fig. 1). We now know that the features were large sea ice pressure ridge fields or fragments. These ice rubble formations may form at sea, or may develop on shoals or near beaches during ice movement and pressuring events.

Kovacs[7] reported on very large floating ice rubble fields in the waters north of the Bering Strait, at the latitude of the Arctic Circle, and islands or ramparts of pressured ice 14 m high grounded on the west side of Prince of Wales Shoal. Large grounded pressure ridge formations have been observed in Landsat imagery off the Yukon River Delta.[5,16,19] Hunter et al.[6] and Thor et al.[20,21,22] noted that the sea floor in Norton Sound and along the northeastern Bering Sea Coast is highly scarred by ice keels pushed about during winter ice movement or during breakup, when the grounded ice formations or fragments of them are at first set adrift and then recontact the seabed.

The existence of large sea ice formations in the northern Bering Sea and Norton Sound area is of concern today, as these features may represent the severest ice conditions that an offshore structure placed in these waters would have to resist. In addition, the deep keels of the ice formations would represent a threat to bottom-founded structures should contact occur.

a. This formation was said to be over 12 m high. Note the absence of voids and the dirty appearance of the ice.

b. View of a grounded ice formation near Nome, Alaska, in spring of 1910.

Figure 1. Photographs of Bering Sea pressure ridges taken in early 1900s (courtesy of G.K. Sherrod, Nome Museum).

A reconnaissance was made along the northeast Alaska Bering Sea Coast and the coast of Norton Sound in April 1980 to establish the locations where large sea ice pressure ridge formations occur and to determine their general characteristics. The locations of shore ice pile-up and ride-up events were also documented, as these phenomena also pose a threat to shoreline facilities.

FIELD OBSERVATIONS

On 10 April a reconnaissance flight was made over the Alaska Bering Sea - Norton Sound area (see Figure 2). We flew over loose pack ice from Nome to the Yukon River Delta. About 5 km out from the

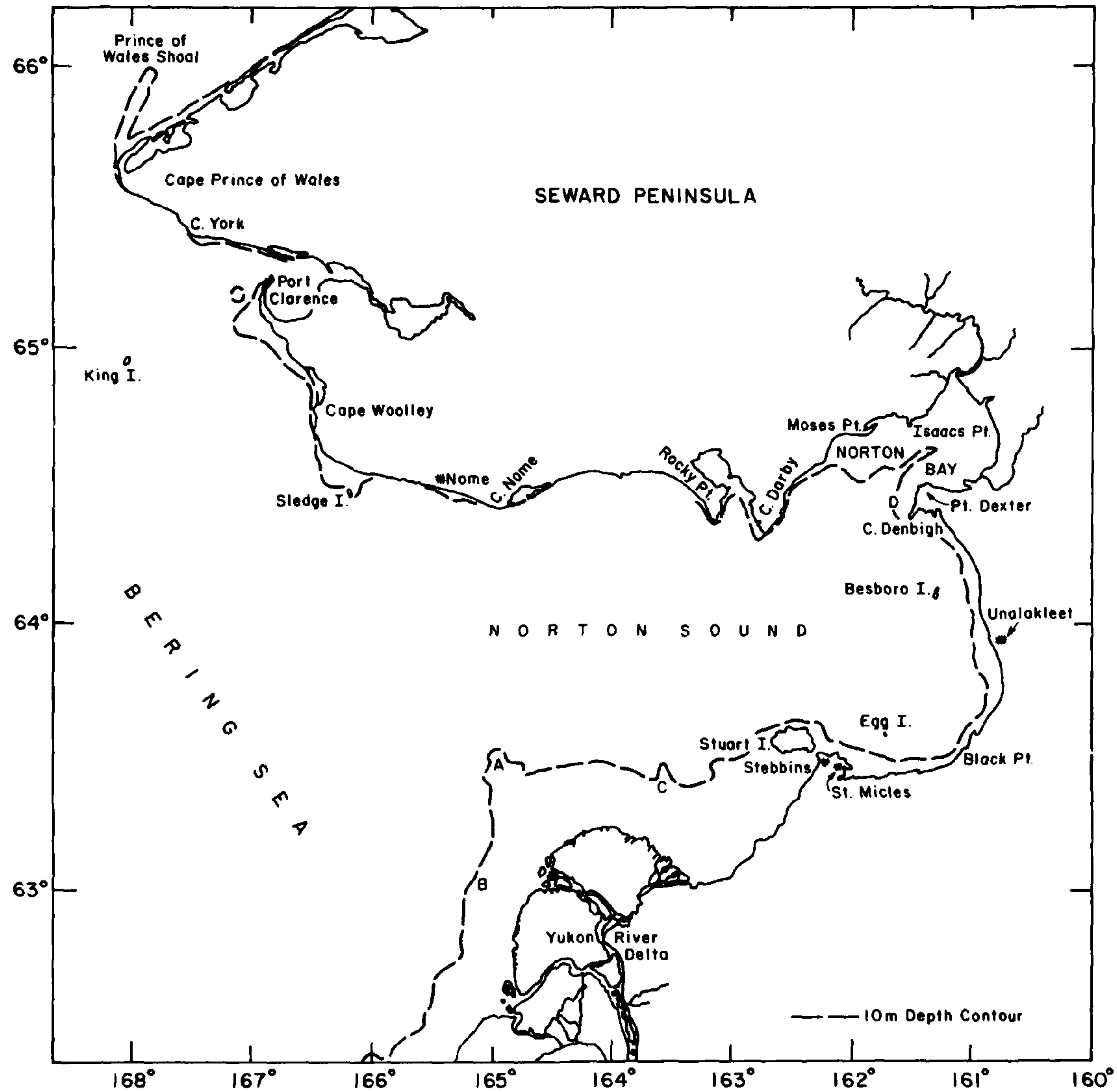
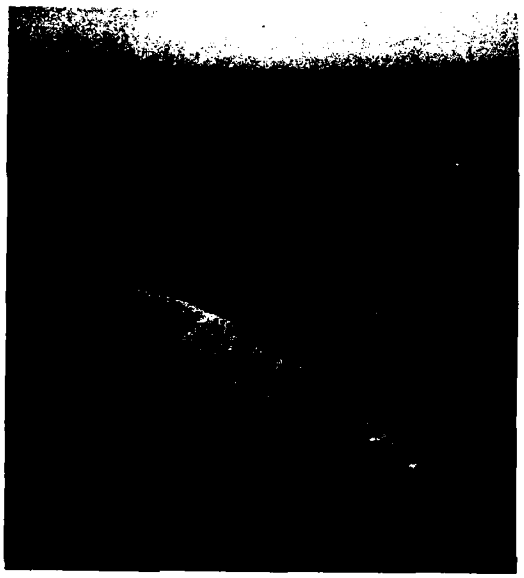


Figure 2. Area map.

fast ice surrounding the Yukon Delta there was an open water area, in the center of which (position A in Fig. 2) were several large grounded ice formations (Fig. 3). Bathymetric maps show shoals in this area which rise to within 5 m of the surface.

Along the fast ice edge, large grounded ice rubble formations were observed. These formations were typically 200 to 1000 m long and 50 to 300 m wide. They tended to be isolated features, separated from one another by many kilometers of level or rubble ice of low relief. Further inland from the fast ice edge smaller ice pile-ups existed.

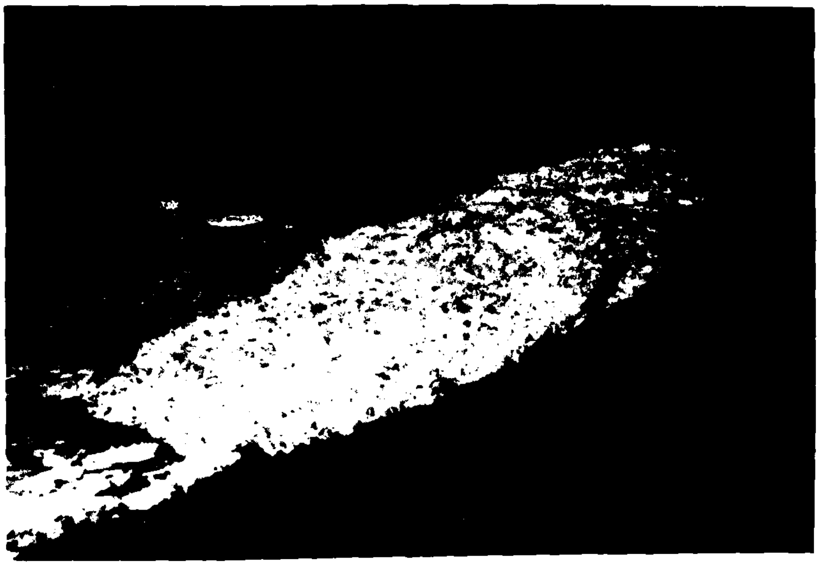
a. Fragments of broken ice exist along fast ice edge at bottom of photograph.



b. Close-up aerial views of the two ice formations shown above.

Figure 3. Two ice ridge formations believed grounded on ribbon-like shoals off the Yukon River Delta.[5]

These were also of considerable height but were often found to be surrounded by undeformed sea ice. Virtually all the ice formations observed were formed by ice piling up under compressing forces and not as a result of shear deformation, for example along the fast ice edge. Ridge orientation within the ice rubble fields and ice pile-ups



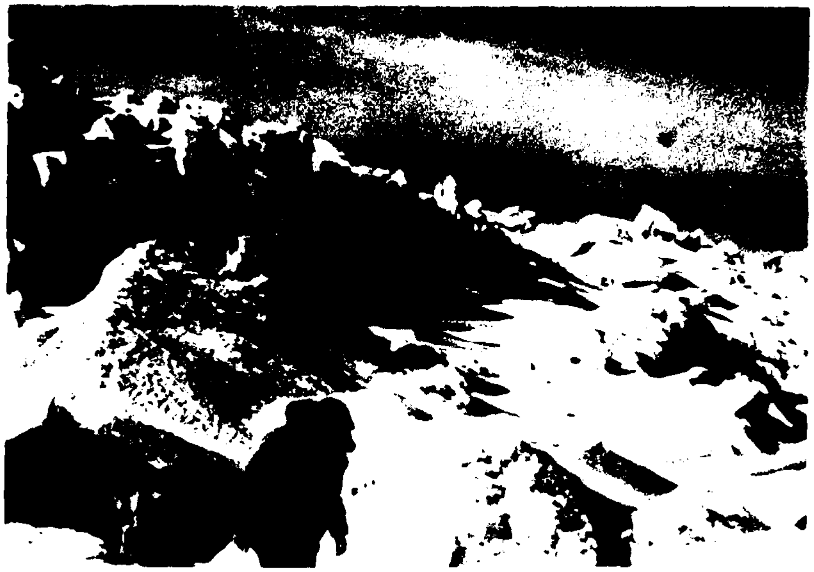
a. Aerial view.

b. Ground view (arrow points to man).

Figure 4. Grounded ice formation one.

on shore indicated that these formations occurred during ice movement from virtually every compass quadrant.

The largest concentration of grounded pressure ridges in Norton Sound was observed off the Yukon River Delta between positions B and C in Figure 2. A number of these ice formations were visited to determine their relative height, the thickness of their ice blocks, and local water depth.



c. Close-up view showing ice block thickness variation and dirt incorporated in the ice rubble.

Figure 4 (cont'd). Grounded ice formation one.

The first ice rubble pile visited is shown in Figure 4. The fast ice was in contact with this formation only at the southeastern end. Drift ice along the north side was estimated to be moving westward at 3 to 4 knots. The formation was estimated to be 75 m wide and over 250 m long. It consisted of ice blocks typically 35 cm thick, but many ice blocks over 1 m thick were noted (Fig. 4c); the thicker ice consisted of previously ridged and rafted ice fragments. The ice formation was grounded in 4.1-m-deep water and reached a height of over 14 m.

Ice formation two (Fig. 5) was grounded in 6.0-m-deep water and was 12 m high.

Ice formation three (Fig. 6) was situated in water 4.2 m deep and was 14 m high.

Ice formation four (Fig. 7) comprised ice blocks 25-30 cm thick; it had a ridge height of 13 m and was grounded in water 7.5 m deep.

Ice formation five (Fig. 8) consisted of ice blocks 30 to 35 cm thick and it was estimated to be 75 m wide and 200 m long. The vertical ice sheet behind the observer extended 3.8 m above the 13-m-high ice rubble at its base. The water depth beside the ridge was 3.1 m.

a. Looking south.

b. Surface view of the south face of the ice rubble.

Figure 5. Grounded ice formation two.

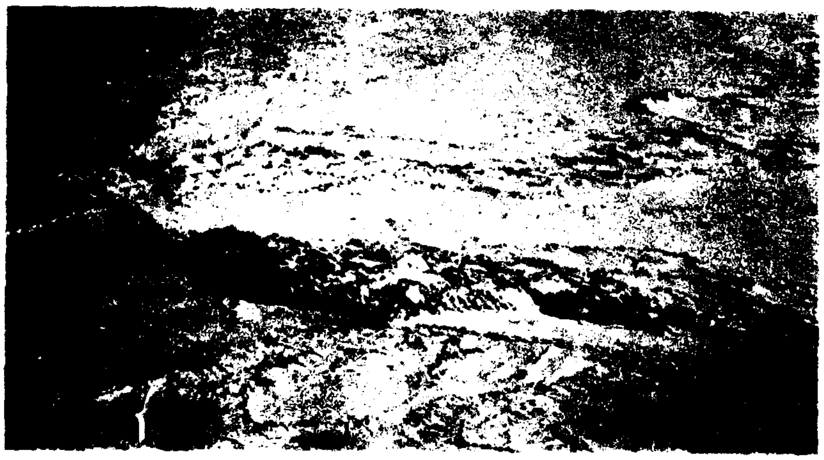


Figure 6. Grounded ice formation three. Top of photograph is east.

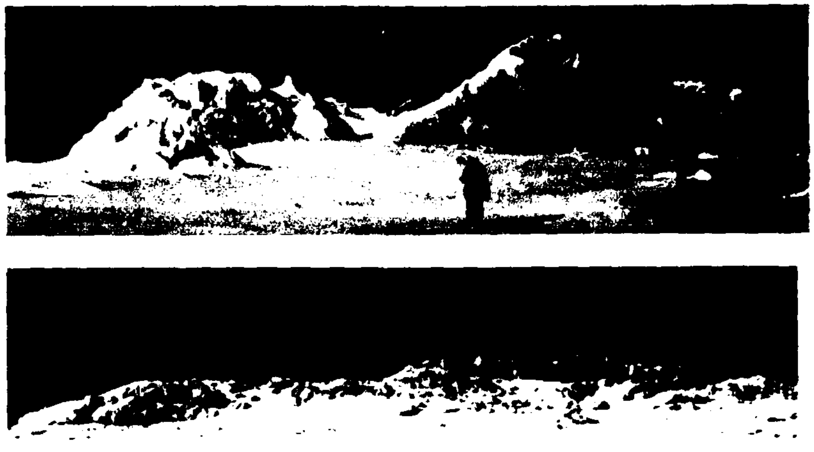


Figure 7. Grounded ice formation four (top). Note man on top of ridge and dirt incorporated in the ice rubble (bottom).

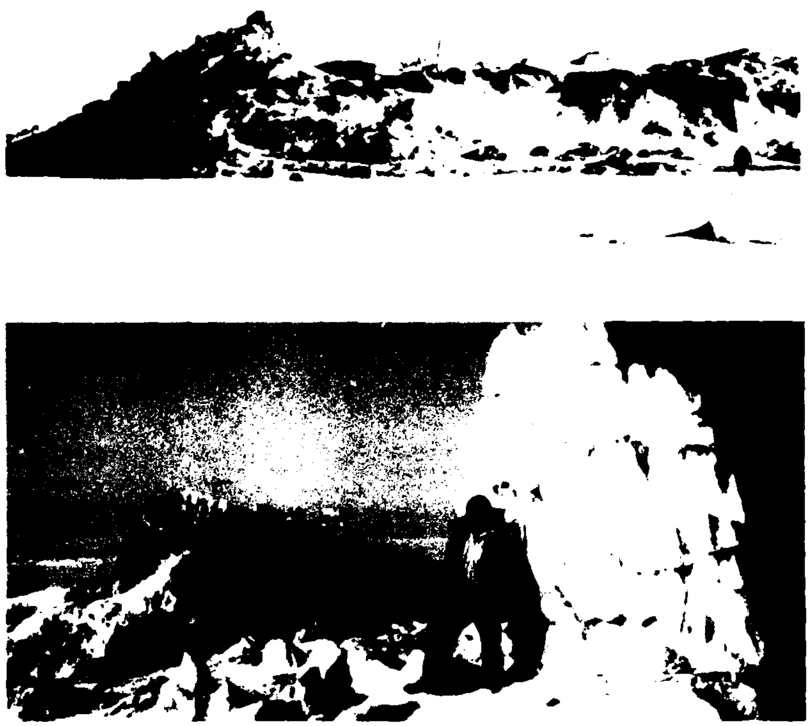


Figure 8. Grounded ice formation five. Note the dirt incorporated in the ice rubble. The vertical ice sheet was highly fractured and scoured as a result of being pushed upward through the surrounding ice blocks. Ice block width:thickness aspect ratio in the sheet was 1:1 to 1:1.5.

Figure 9. Grounded ice formation six. Arrow points to man.

Figure 10. Northwestern edge of fast ice off the Yukon River Delta. The ice formation shown closest to the fast ice edge in Figure 3 is located to the center right.

Ice formation six (Fig. 9), also estimated to be 75 m by 200 m, was 14 m high and grounded in 6.2 m of water.

A wide ice formation was observed near site A in Figure 2. Its size and location helped to fix the northwesternmost position of the fast ice at the time of our reconnaissance (Fig. 10). Two soundings taken 200 m apart alongside the ice formation gave water depths of 9.7 and 10.0 m. The ice blocks in the formation varied from 30 to 40 cm thick and were pushed into ridges up to 12 m high.

Ice formation seven is shown in Figure 11. The average ridge height in this formation was estimated to be between 5 and 6 m and most of the ice blocks were 30 to 45 cm thick. Some, from pressure ridges or previously rafted ice, were over 1 m thick. The highest

Figure 11. Grounded ice formation seven. In aerial photograph, fast ice is to left, pack ice to right.

ridge was 17 m high. A sounding taken beside the ridge gave a water depth of 11.2 m.

Ice formation eight (Fig. 12) was grounded in 3.0-m-deep water. It was approximately 150 m by 200 m in size and had a peak ridge elevation of 11.5 m.

Ice formation nine (Fig. 13) consisted of ice blocks up to 2 m thick and was grounded in water 8.9 m deep. The two highest ridges in the formations were over 11 m high.

Ice formation ten (Fig. 14) was grounded in 4.5-m-deep water. Ice blocks in this formation varied from 40 cm to 2 m in thickness and formed ridges up to 9 m high.

Ice formation eleven (Fig. 15) was 9 m high and was grounded in 8.5-m-deep water near position C in Figure 2. Collapse of a portion of the ridge revealed a core of fragmented ice blocks refrozen into a solid mass (Fig. 15b). On the left side of the ice formation the

Figure 12. Grounded ice formation eight. Note ice rubble and dirt.

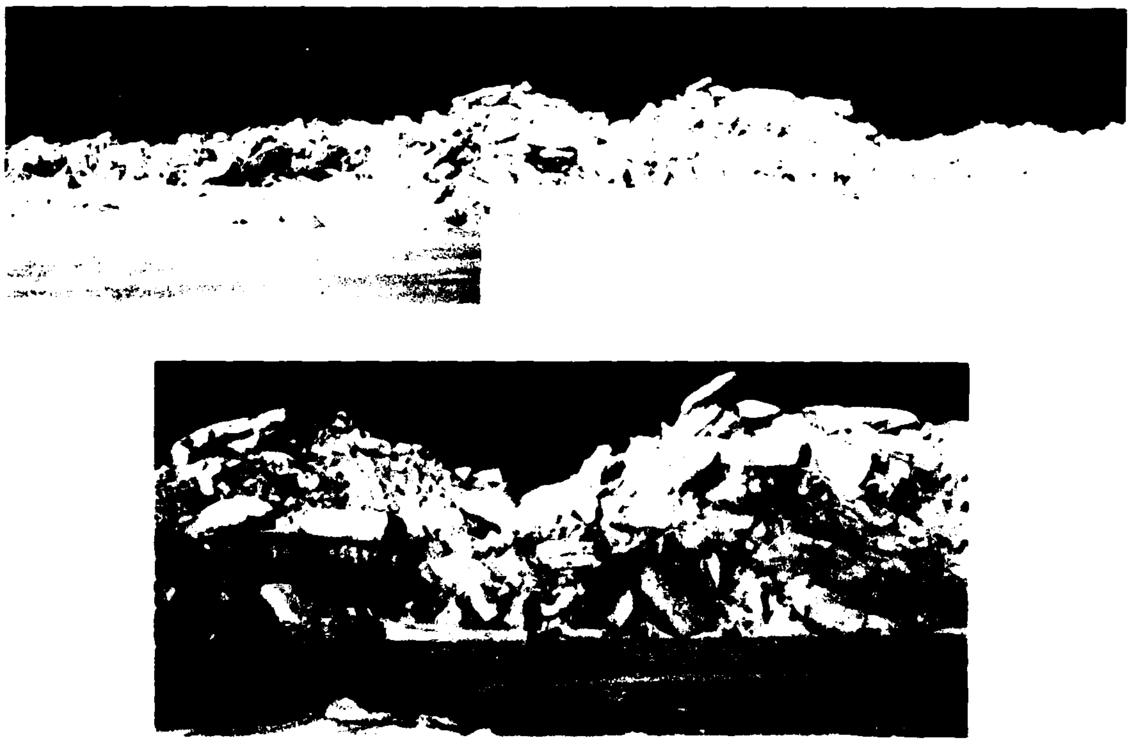


Figure 13. Grounded ice formation nine.

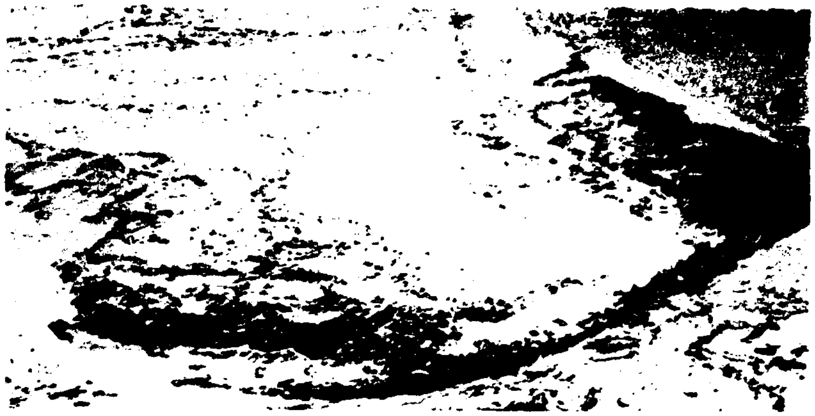


Figure 14. Grounded ice formation ten (at extreme right).

a. Aerial view.

b. Refrozen fragmented ice in ridge core.

Figure 15. Grounded ice formation eleven.

c. Portion of original ice sheet.

Figure 15 (cont'd). Grounded ice formation eleven.

Figure 16. Air (top) and surface (bottom) views of grounded ice formation near Stebbins. The village is along the coastline at upper left in both photographs.

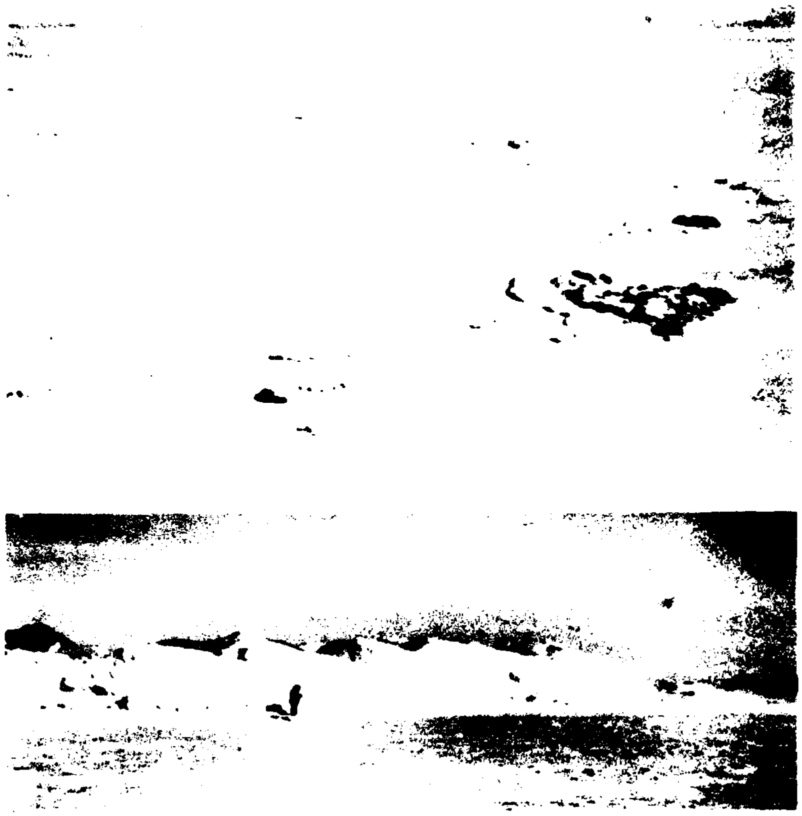


Figure 17. Four grounded ice formations near Isaacs Pt. (extreme upper left in top photo, and at left behind the near ground ridge formations in bottom photo). Two other formations are shown in the distance at the right in bottom photo. Note the dark color of the second largest ridge which is due to sediment in the ice rubble.

30-cm-thick ice sheet from which the pressure ridge formed could be seen (Fig. 15c).

We also observed grounded ice formations in fairly sheltered locations, such as one over 3.5 m high in 3.9 m of water near the village of Stebbins (Fig. 16). This ridge was composed of ice blocks 10 to 15 cm thick. In another somewhat sheltered area off the southeast coast of Isaacs Pt. (Fig. 2) four grounded ice formations were observed, each 4 m or more in height. These formations are shown in Figure 17. The largest one in area was grounded in 2.6 m of water.

Large grounded ice formations were also observed paralleling the 10-m depth contour from Cape Denbigh to Pt. Dexter (Fig. 18), off the coast of Cape Darby, Rocky Point, Cape Nome, and the south side of

Figure 18. Grounded ice formation west of Cape Denbigh.

Figure 19. Five-meter-high ice formation grounded in 6.3 m of water off Port Clarence.

Sledge Island, off Port Clarence spit (Fig. 19) and along the coast between Cape York and Cape Prince of Wales.

DISCUSSION

Ample evidence has been presented in this report to show that many massive grounded ice formations can be found off the Norton Sound and northeastern Bering Sea coasts of Alaska. Similar ice formations have been observed near St. Lawrence and St. Mathews Island (Fig. 20). Many of these features have been observed to have relatively solid cores, a result of the freezing of water within the ridge voids. The sources of this water are an occasional rainfall and

Figure 20. A view from Bull Sea Point on the northeast coast of St. Mathews Island in the southeastern Bering Sea showing several offshore grounded ice rubble formations (see arrows). (Photo source, 1976 Arctic Bulletin.)

surface snow or ice that melts during midwinter thaws. Both occurred in the Norton Sound region during the winter of 1979-80. The solid cores are also the result of pressure consolidation during ridging.

Most of the grounded ice formations were found to be quite dirty (Fig. 21). Some of this material was incorporated into the ice during growth, either by the freezing of silt-laden water or by the incorporation of dirt-laden frazil ice into the growing ice sheet. Drake et al.[4] have shown that significant suspended sediment exists in the water beneath the ice in the Yukon River Delta region during the winter. However, most of the dirt observed in the ice rubble was the direct result of ice interaction with the sea floor. During ridge-building, portions or fragments of the ice sheet were forced downward against the seabed and then pushed back upward, bringing sediment with them to all parts of the rubble pile. Through this action sediment is gouged up and redistributed by ice or current transport.

The sequence of events associated with the formation of the isolated sea ice rubble formations surrounded by undeformed ice is as

Figure 21. Typical sediment-laden ice ridge formations.

follows. A major ice movement event occurs, perhaps in conjunction with a rise in sea level. Fragments of the moving ice sheet come in contact with the seabed, initiating further ice-bed and ice-ice interactions. A large accumulation of pressured ice forms at this site of resistance. Under the driving force of wind or current, the remaining drift ice is advected out of the area, leaving behind the grounded ice formations. In time the surrounding waters refreeze. The resulting ice sheet is more resistant to movement, being held fast by the grounded ice. The grounded ice helps to stabilize the fast ice

by providing anchorage to the sea floor and allows the fast ice to extend farther off the coast into deeper water than would otherwise be possible. In this respect, the grounded ice formations along the Yukon Delta do what the large ice formations in the grounded ice zone along the Beaufort Sea coast have been shown to do.[8 9]

The lateral confining support provided by a stationary ice field is of course lost during the time an ice rubble formation is exposed to open water or loose drift ice. When this occurs, the exposed outer perimeter of the ice rubble formation undoubtedly calves off. The remaining keel slope is probably similar to the 50° to 90° keel slopes measured on ice formations that had experienced similar loss.[7 8] For grounded ice formations that do not experience calving, the keel slope angles are probably similar to those of first-year pressure ridges, which average 33°.[8] The interior ridge slopes of the ice rubble formations were not measured, but these too are believed similar to those of first-year pressure ridges, which average about 24°.[9]

Other processes associated with ice rubble formations, pressure ridges and pile-ups are beyond the scope of this report. However, models have been developed to describe the force levels and other formation processes associated with the building of these ice formations.[1 10 11 12 13 14 15 18]

A fundamental question for those concerned with the design of offshore structures is: Do these massive ice formations lift off the seabed during high storm surge events and then drift about?

During this study one ice formation (Fig. 22) was observed from the fast ice edge, east of position A in Figure 2, moving west. A

Figure 22. Ice formation observed moving with the current.

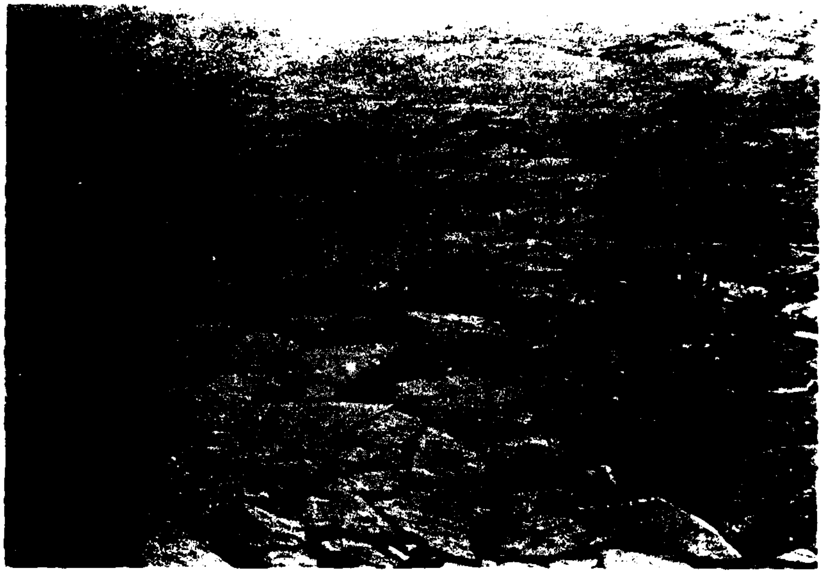


Figure 23. Ice rubble formation (see arrow) in a broken ice field observed moving along the fast ice edge which is near top of photo.

second ice formation (Fig. 23) was observed moving with a broken ice field near position C in Figure 2. Another observed from the air (Fig. 24) appeared to be sailing westward through thin ice west of Rocky Point. However, this was not verified by observations from the fast ice as a landing could not be made. The following personal accounts of large ice formations sailing about are of interest.

In the spring of 1973, while hunting on the sea ice southwest of Cape Wooley, John I. Pullock, a King Islander, encountered an ice formation which he estimated to be 7 m high, 30 m wide and perhaps 100 m long. It was moving from west to east under the driving force of the current as the winds were from a different direction. As the ice formation moved it fractured both thick and thin ice in its path. He and other hunters on the ice had to move toward shore in order to get out of its way.

In May 1973 Ralph Olanna of Nome, his father and his uncle were returning from the west around Sledge Island (see Figure 2). They were in a 5.5-m-long aluminum boat and were trying to get to Nome, as a storm was building fast. About 2 to 4 km offshore, somewhat west of Nome, strong winds and high waves prevented them from proceeding. They were forced to pull their boat up onto a large ice formation, which Ralph estimated was 9 m high and 40 m in diameter. The ocean

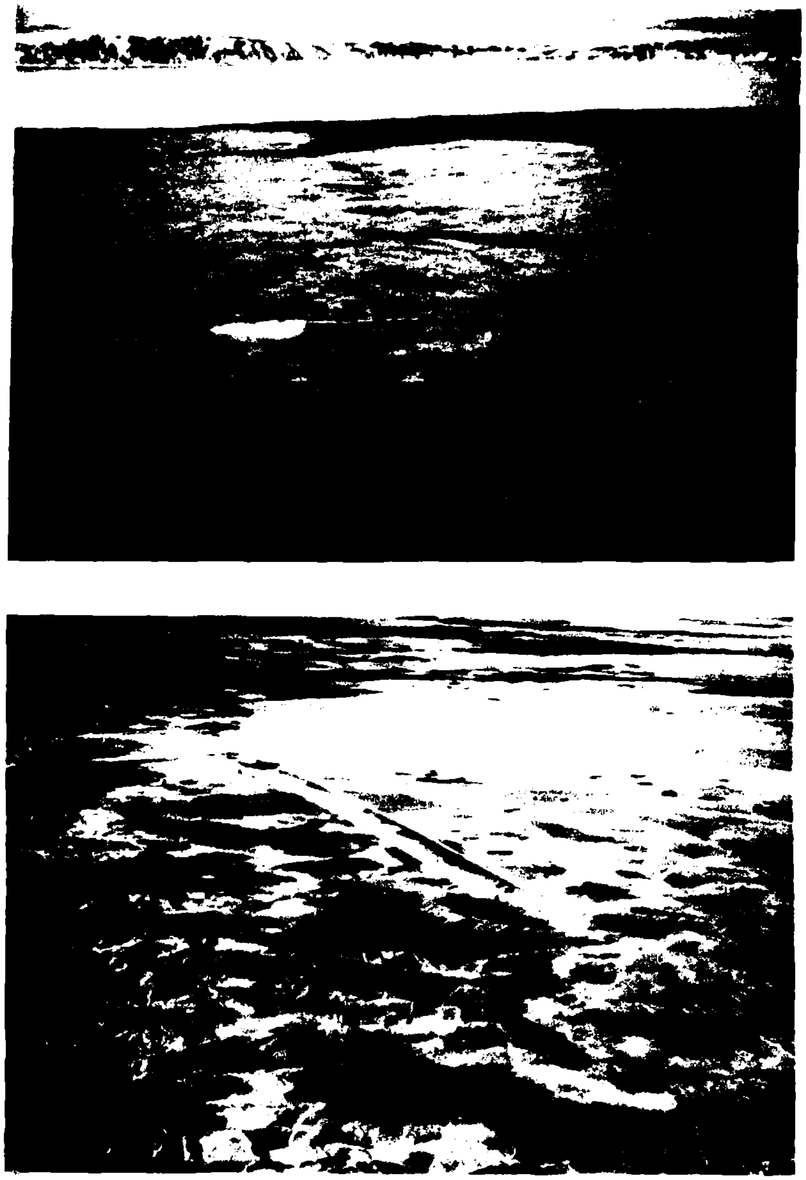


Figure 24. Ice formation believed to be moving with the current through thin ice.

swells kept getting bigger, reaching 5 to 6 m from trough to crest. The three men had to pull their boat higher and higher, nearly to the top of the ice formation, to prevent it from being washed away. Parts of the ice rubble broke off from time to time under the beating from the waves. Four days later, after drifting about 130 km eastward, they were picked up by a Japanese research vessel about 50 km south of Rocky Point. This vessel had been forced into Norton Sound by ice movement during the storm.

The observations of early sailors coupled with the above accounts clearly indicate that large sea ice rubble formations can be found drifting in the waters of the Bering Sea and Norton Sound. Since extreme storm surges in Norton Sound are of the order of 5 m, while surges of 2 to 3 m are not uncommon,[2 16] it is reasonable to assume that some grounded sea ice rubble formations can be lifted off the seabed and set adrift during high sea rises.

The displacement and grounding of these ice formations is known to produce ice keel gouges in the sea floor sediments.[6 20 21 22] The potential severity of this occurrence to bottom-founded facilities is unknown. It is known that "To improve communications during the months when navigation was not possible a telegraph line was constructed in 1880 from Nome to Fort Gibbon (Tanana) utilizing a sea cable between Nome and St. Michaels, the first in the territory."[2] The Nome Daily Gold Digger at the turn of the century also makes reference to the "Signal Corps U.S. Army" laying telegraph cables in 1903 across Norton Sound between St. Michaels and Port Safety, a distance of about 160 km. It would be interesting to learn the service history of these cables to determine whether drift ice had cut the cables, and if so, the frequency of occurrence.

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